ISLAND FOX MONITORING AND DEMOGRAPHY ON SAN NICOLAS ISLAND—2008

FINAL REPORT

Prepared For

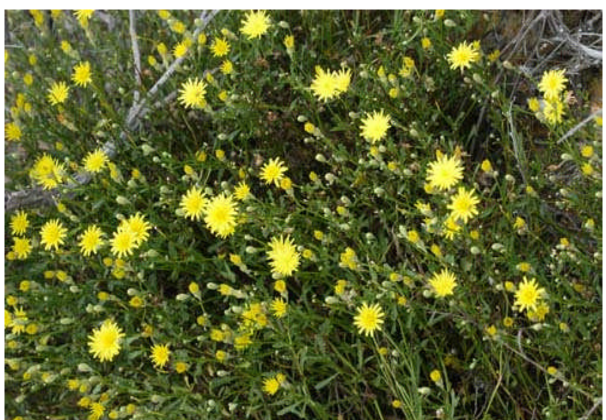
Naval Outlying Landing Field, San Nicolas Island Ventura County, California

Under Cooperative Agreement No. N62473-07-2-0018

And

Naval Facilities Engineering Command, Southwest
San Diego Naval Station, San Diego, California

July 2009



ISLAND FOX MONITORING AND DEMOGRAPHY ON SAN NICOLAS ISLAND–2008

FINAL REPORT

Prepared By

David K. Garcelon
Brian R. Hudgens

Institute for Wildlife Studies
P.O. Box 1104
Arcata, California 95518

Prepared For

Environmental Office, Naval Outlying Landing Field, San Nicolas Island,
Ventura County, California

AND

Naval Facilities Engineering Command, Southwest
San Diego, California
Agreement No. N62473-07-2-0018

July 2009

Recommended citation:

Garcelon, D. K. and B. R. Hudgens. 2009. Island Fox Monitoring and Demography on San Nicolas Island–2008. Unpublished report *prepared by* the Institute for Wildlife Studies, Arcata, California. 26 pp.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

The island fox (*Urocyon littoralis*) is California's only endemic carnivore, with a range limited to six of the eight California Channel Islands (Moore and Collins 1995). Despite its small size—it is the smallest fox species in the United States—it is the largest native terrestrial mammal found on the California Channel Islands. Morphological and molecular studies (Collins 1982, 1993; Gilbert *et al.* 1990, Wayne *et al.* 1991, Goldstein *et al.* 1999) justify the current classification of the island fox as a separate species from the mainland gray fox (*U. cinereoargenteus*; Wilson and Reeder 1993) and support the classification of a separate subspecies for each island (Hall 1981, Moore and Collins 1995). The island fox is listed as threatened by the state of California (California Department of Fish and Game 1987), and the subspecies occurring on San Miguel, Santa Rosa, Santa Cruz, and Santa Catalina islands are federally listed as endangered (Federal Register: Volume 69, Number 44, Pages 10335–10353).

In early 2000, foxes on San Nicolas Island, California (*U. l. dickeyi*) and those on San Clemente Island, California (*U. l. clemente*) were considered to be the only subspecies maintaining viable populations (Suckling and Garcelon 2000). The four remaining subspecies suffered marked declines in the mid to late 1990s. The subspecies on all three northern California Channel Islands (Santa Cruz, San Miguel, and Santa Rosa) were in imminent danger of extinction owing to predation by golden eagles (*Aquila chrysaetos*; Roemer *et al.* 2001) and the Santa Catalina Island subspecies, declined from an estimated 1300 in 1989–90 (Roemer *et al.* 1994) to about 100 as a result of an outbreak of canine distemper virus that swept through the population in 1999 (Timm *et al.* 2000). Fortunately, captive breeding programs on all four islands have been successful, and releases of captive-born foxes to the wild began in 2004. Island-wide trapping results in 2004 indicated that both subpopulations on Santa Catalina Island had reached the recovery goal set by Kohlmann *et al.* (2003, 2005) of at least 150 individuals in each subpopulation. Based on the trapping results, the subpopulations were considered recovered and a decision was made to close the captive breeding facility and release all captives to the wild.

The aforementioned declines of island fox subspecies emphasize the importance of monitoring population parameters of the San Nicolas Island subspecies. In the summer of 2000, the Institute for Wildlife Studies (IWS) began a fox-monitoring program on San Nicolas Island by establishing three capture-recapture trapping grids to evaluate the current status and demography of the subspecies and to monitor changes in population parameters. Trapping on the grids has been repeated each year since 2000 (Juola *et al.* 2002, Schmidt and Garcelon 2003, 2004, Garcelon and Schmidt 2005, Schmidt *et al.* 2006, 2007) and this report describes results for the 2008 trapping session. Where appropriate, comparisons are made with the results from the seven previous years of monitoring.

STUDY AREA

San Nicolas Island is the westernmost of the four southern California Channel Islands (Fig. 1). San Nicolas has been owned and operated by the United States Navy since 1933 and is closed to the public. At approximately 98 km from coastal Ventura County, California, it is the farthest of the eight California Channel Islands from the mainland. The 58-km^2 island is approximately 13 km long and 5.5 km wide with elevation ranging from sea level to 278 m. It is the fourth smallest Channel Island, larger only than San Miguel, Santa Barbara, and Anacapa islands. The island is roughly a plateau, with arroyos cutting down to the shoreline. The island is composed primarily of coastal scrub habitat (42% of island area), barren areas (24%), and grassland habitat (12%) (Halverson *et al.* 1996). From west to east, the sampling grids (Fig. 2&3) are dominated by coastal scrub and inland dune habitats (Redeye grid), coastal scrub (Tuft's grid), and grassland and coastal scrub (Skyline grid). The combined area (*i.e.*, the area created by connecting the outer trap locations of each grid) of the three grids was 6.7 km^2 or 11.6% of the total island area. The combined effective trap area (see Methods section for definition) for the grids in 2006 was 10.6 km^2 or approximately 18% of the total island area (Fig. 3). The Tuft's grid contains the greatest density of coyote brush (*Baccharis pilularis*) and coast goldenbush (*Isocoma menziesii*) and both the Tuft's and Redeye grids contained high densities of *Lupinus* and *Astragalus* species and the exotic sea fig or ice plant (*Carpobrotus chilensis*), which foxes are known to consume.

Fig. 1. San Nicolas Island, California viewed from the west (left) and from the north (right).

METHODS

Trapping and Handling

Foxes were trapped on the same three rectangular demography grids (Tuft's, Skyline and Redeye grids; Fig. 2 & 3; Table 1; Appendix A) used since the start of the fox monitoring program in 2000. Traps (23 x 23 x 66 cm box traps, Tomahawk Live Trap Co., Tomahawk, WI) on all three grids were placed at 250-m intervals and opened for six consecutive nights. Unlike previous years when traps were opened for six consecutive nights, traps were only left open for five consecutive nights in 2007, necessitated by working around scheduled military operations and weather. Traps were baited with dry cat food, and a loganberry paste attractant (On Target A.D.C., Cortland, IL). Traps were covered with burlap and vegetation to provide protection from the sun and wind, and the bottoms were lined with grass to cover the metal of the trap and as bedding material for captured foxes. Traps contained "bite bars" (20-cm section of 1.3-cm-diameter polypropylene tubing attached to the inside of the trap with flexible wire) that captured animals could bite without damaging their teeth. As foxes routinely dig under traps to retrieve the bait when it falls through the mesh floor, a piece of plastic was placed behind the treadle to prevent it from falling out of the trap.

Data recorded on the first capture of each fox included date, grid name, trap number, passive integrated transponder (PIT) tag number (used as a unique identifier), sex, weight (to nearest 0.025 kg), ectoparasites (fleas, ticks, lice, ear mites) present, eye condition, reproductive condition and tooth condition. If an animal was not previously tagged, a subcutaneous PIT tag was inserted between and just anterior to the scapulae using a single-use sterile needle and syringe. Foxes were aged according to tooth eruption and dentin exposure patterns relating to wear on the first upper molar (Wood 1958, Collins 1993) and assigned to one of five age classes. Foxes were classified as pups (age class 0), yearlings (age class 1: ca. 1 year old), young adults (age class 2: ca. 2 to 3 years old), mature adults (age class 3: ca. 3 to 5 years old) and old adults (age class 4: ≥ 5 years old). Foxes were also assigned a relative body condition (1-5), with a 1 being a skinny animal with little or no body fat and a 5 being obese. We also noted any injuries or physical abnormalities, including those that appeared to have been related to the animal's capture.

The Institute's staff veterinarian conducted external physical examinations (*e.g.*, heart rate and rhythm, lung condition, abdomen palpation, general body condition) and examined the ears with an otoscope (for mites, inflammation, and tumors) on a sample of foxes captured. In addition, a subset of foxes captured on all grids was vaccinated against canine distemper virus and rabies virus. Ear mites were collected from a sample of the foxes captured to aid in an inter-island study on the effect of these ectoparasites on fox health.

Obtaining a weight on a captured fox prior to it being examined.

Foxes are given examinations from head to tail.

Up to 10 ml of blood was collected from the femoral vein or artery or jugular vein of select foxes for genetic and serologic analysis, and feces were collected when available. Serum was extracted from whole blood after centrifugation using a sterile pipette. Serum samples were split into 1 ml aliquots, each of which was placed in a 1.8-ml cryovial prior to freezing.

We determined if there were significant differences in mean body weight by sex or grid, or if there was a significant sex-by-grid interaction effect, using analysis of variance. Mean body weight was compared among grids for a given sex using Tukey's HSD multiple comparison test. Except as noted below, all analyses were conducted with SAS (SAS Institute, Inc., Cary, NC, USA 2001) software. For all tests of significance, we used an alpha of 0.05.

Table 1. Island fox demography grid descriptions, San Nicolas Island, California.

Grid	Years trapped	No. of traps	Grid configuration	Inter-trap distance (m)	No. of nights trapped each year	Perimeter area (km^2)[a]	Percent of total island area[b]	Primary vegetation types within grid perimeter (within effective trap area for 2006)[c]
Redeye	2000–2008	48	6 x 8	250	6 (5 in 2007)	2.19	3.8	47% (42%) inland dune; 46% (49%) coastal scrub; 5% (5%) barren
Skyline	2000–2008	50	5 x 10	250	6 (5 in 2007)	2.25	3.9	52% (52%) grassland; 43% (38%) coastal scrub; 3% (7%) barren
Tuft's	2000–2008	50	5 x 10	250	6 (5 in 2007)	2.25	3.9	90% (89%) coastal scrub; 4% (4%) barren; 2% (2%) inland dune

[a]Represents the area created by connecting the outer trap stations.

[b]For grid perimeter only, not the effective trap area.

[c]Percentages are rounded to the nearest whole number. Effective trap area is the sum of the grid perimeter area and the strip surrounding the grid that is likely influenced by the traps.

[d]See Fig. 2 and Fig. 3 for grid locations and Fig. 3 for effective trap area polygons.

Population Size, Density, Growth Rate, and Survivorship on Demography Grids

We used Pollock's robust design (Pollock 1982, Pollock *et al.* 1990, Kendall *et al.* 1995, Kendall 2001) within program MARK (version 5.1, White and Burnham 1999) to estimate adult fox population size (> age class 0) on each demography grid. This design assumes that fox populations are demographically closed (*i.e.*, no significant natality, mortality, immigration, or emigration occurs during the trap period) within a trapping session but allows for open populations between years. Because this analysis accommodates and uses information from previous years' capture histories, for each grid we simultaneously estimated population size for all years during which it was trapped. We note that estimates for previous years closely match those presented in earlier reports generated from program CAPTURE. For each grid we used the density estimator, D=N/A, where N is the estimate of the grid population size (from program MARK) and A is the area influenced by the trap grid. This area was the sum of the grid perimeter area and an additional strip around the grid perimeter; the strip width was calculated from an estimate of the mean maximum distance foxes moved (MMDM; Wilson and Anderson 1985) between captures that was generated by program CAPTURE. Pups (age class 0) were excluded from estimates of population size and density due to their close association with adults––the relatively short movements of the less mobile pups could decrease the MMDM, resulting in a smaller area of influence and inflated density estimates.

This year we also used a second method of estimating island fox population density for each of the grids. We employed Program DENSITY (Efford et al. 2004) which applies spatially explicit capture-recapture, using the locations where each animal is trapped to fit a spatial model of detection. The resulting estimate of population density are unbiased by edge effects and incomplete detection. The program uses inverse prediction and maximum likelihood as alternative methods for fitting the spatial detection model.

Population growth rates (λ) for the demography grids were calculated as $\lambda = N_{t+1} / N_t$, where N_t is population size (or density in this case) at time t. Thus, $\lambda < 1$ indicates the population is declining, $\lambda > 1$ indicates the population is increasing and $\lambda = 1$ indicates a stable population. To provide the Navy with a long-term prospective to the status and trends of the fox population we have added data collected by the Institute for Wildlife Studies from 2000 through 2007.

We also used program MARK to estimate annual survivorship. We analyzed male and female foxes separately and assigned each fox as either captured first as a pup (age class 0) or first as an adult (age class 1-4). We then estimated parameter values for several models of survivorship, dispersal in and out of sampled areas and probability of capture or recapture. Preliminary analysis indicated that models allowing for yearly differences in capture/recapture probability that did not differ among age class or within a 6-day trapping session best fit the data. Keeping that structure for capture/recapture probability we tested models in which survivorship and emigration from sample plots (i.e., trapping grids) varied by age and year, age alone, year alone or not at all, and immigration into sample plots varied by age or not at all. Models were evaluated in program MARK using the Huggins estimator for data taken according to Pollock's robust design. Included in the output from program MARK is the AIC (Akaike's

information criterion) weight, which is a measure of the probability that a given model is the best of the tested subset of models. In order to estimate survivorship for each year (2000–2008) we calculated a weighted average of the survivorship estimates from all models included in the top 95th percentile of AIC weights. This method of model averaging accounts for both uncertainty in parameter estimates from a given model and uncertainty about which model best fits the data (*i.e.,* best describes the biological processes producing the data).

Testing for Exposure to Canine Diseases

We collected blood samples from 50 foxes to test for exposure canine adenovirus (CAV), canine distemper (CDV) and canine parvovirus (CPV). These viruses were selected due to their epidemic potential and possible fatal outcomes in susceptible individuals. These diseases were also selected because island foxes on San Clemente Island were monitored for exposure to these diseases in 2007 (Garcelon et al. 2008). Blood was collected in the field using venipuncture and the sample was placed in a tube and allowed to clot. While in the field the blood was kept cool using ice packs. The sample was later separated by centrifugation and the serum pipetted off and frozen in cryotubes. The samples were sent for testing to the Animal Health Diagnostic Center at Cornell University in Ithaca, NY.

Photo by Francesca Ferrara

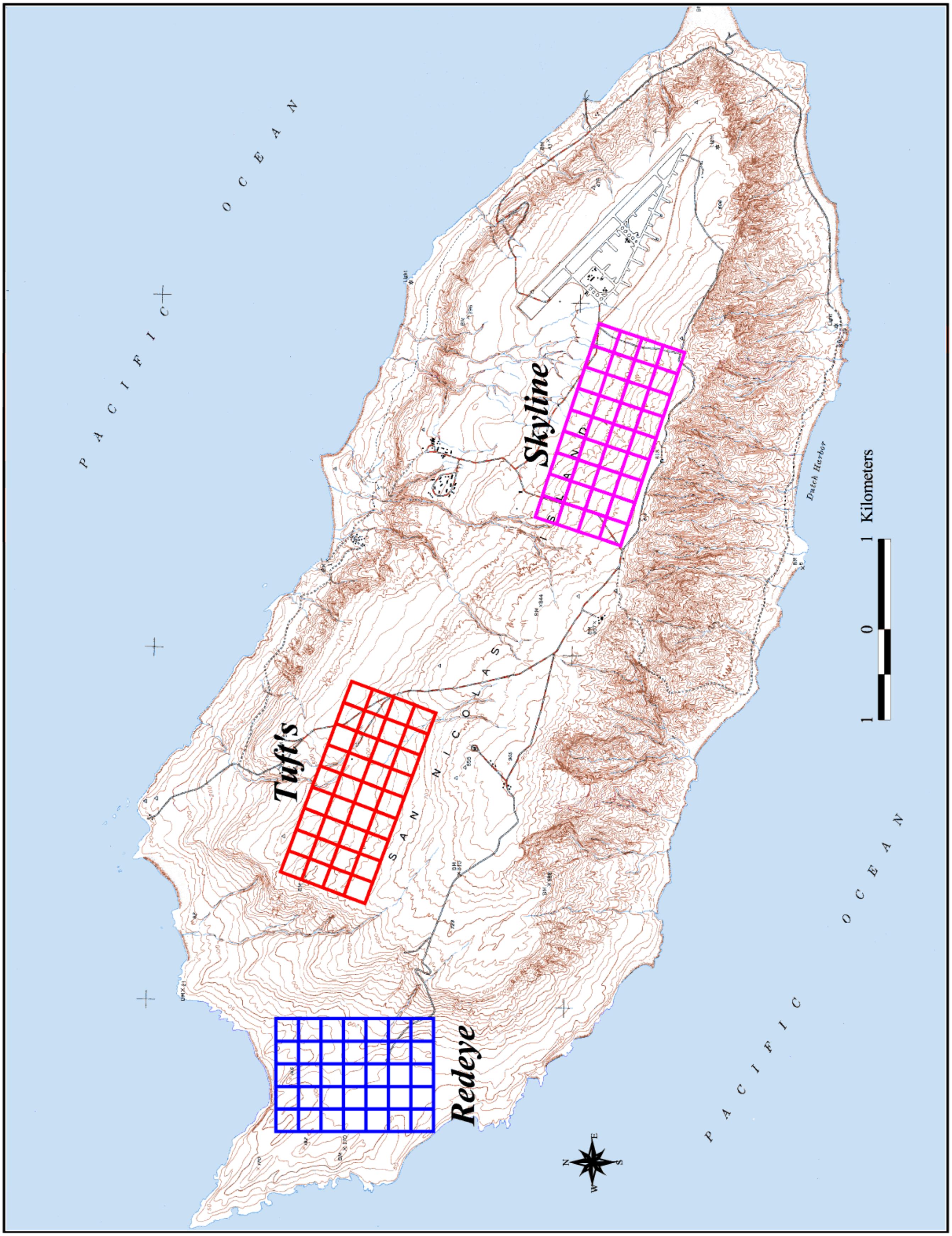


Figure 2. Island fox demography grids, San Nicolas Island, California.

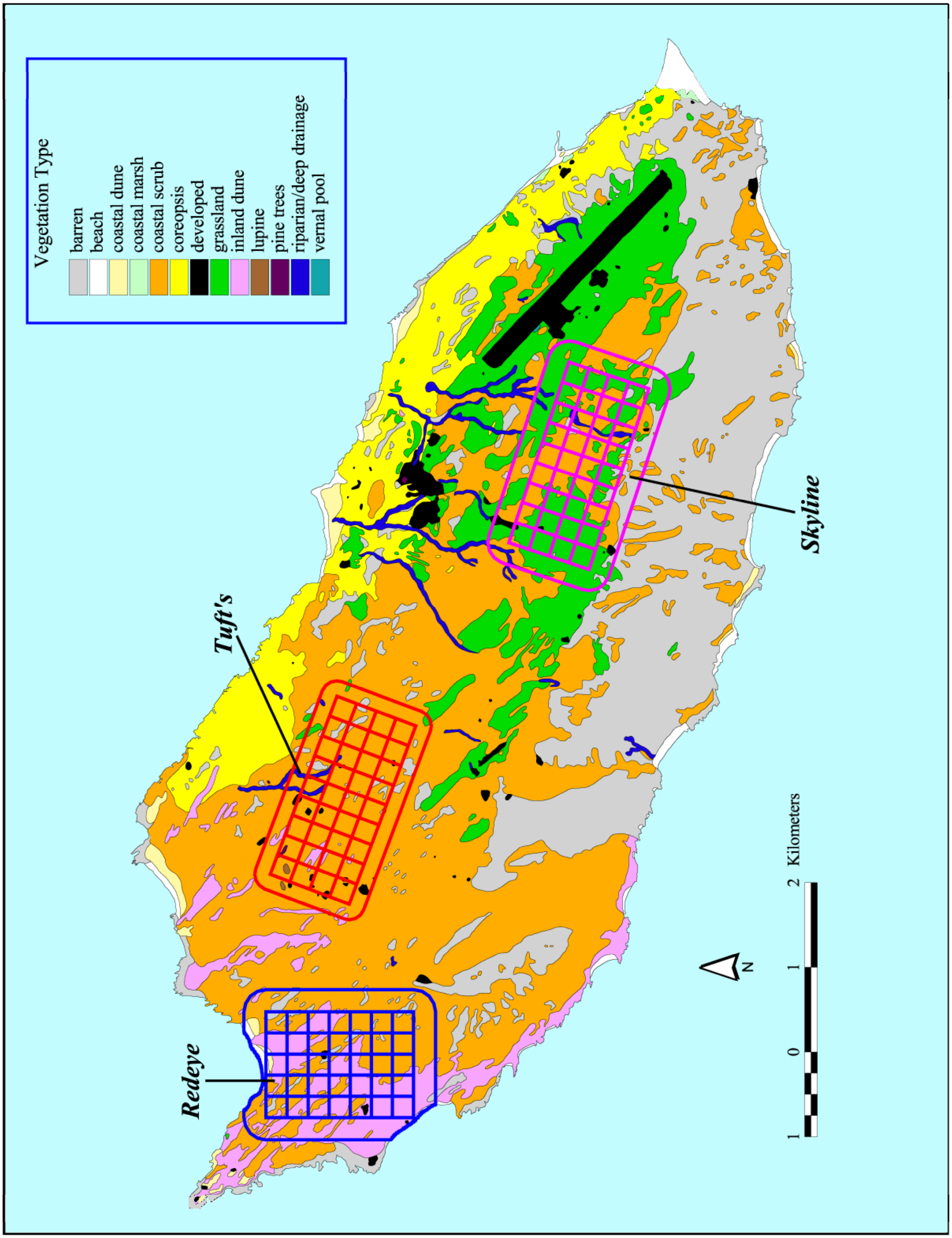


Figure 3. Island fox demography grid effective trap areas (polygon surrounding each grid), 2008, San Nicolas Island, California.

RESULTS

Capture Statistics

We captured 151 adult foxes (69M, 82F) and 22 pups (11M, 11F) a total of 419 times on three grids (Table 2). Fifteen (9.5%) of the adults were captured on a grid for the first time in 2008. The majority of these (53%) were in the age-class one category. Capture success for the three grids averaged 47.5% (Table 2). Foxes were captured an average of 2.6 times. Only one fox was captured on more than one grid during the sampling period (8/15/2008–9/19/2008). An age-class 4 female was captured on four occasions on the Redeye grid in August (the last capture on 8/27/08) and was then recaptured on the Skyline grid one time on 9/9/08. No feral cats were captured in 888 trap-nights.

Age structure varied across the three grids, with age class 1 or 2 making up the largest proportion of individuals for each grid (Fig 4). The small proportion of individuals in age class 3 was manifested again in 2008 on all grids. The number of age class 4 foxes decreased on the Tuft's grid from 31% in 2007 to 23% in 2008.

We obtained serum samples from 50 foxes (19 from Redeye, 16 Tuft's, 15 Skyline). We collected ear mite samples from 27 foxes for an on-going island-wide investigation. We inoculated 90 foxes against canine distemper virus and 88 against rabies virus (Skyline 15, Tuft's 29, Redeye 46).

Physical Condition

In a general assessment of body condition (scale of 1-5, with 1 being thin and 5 being obese), 80% of the foxes examined were in average to good condition, which 13.4% were considered thin or in poor condition. The remaining 6.6% were considered in very good or obese condition.

Fleas (*Pulex irritans*) were found on only 10 foxes (5.7%); no ticks or lice were found on any captured foxes.

Table 2. Island fox demography grid trapping results, 2008, San Nicolas Island, California (see Fig. 2 or 3 for grid locations).

Grid	Dates open	No. Trap-nights	No. Adult males	No. Adult females	Total No. adults	No. Male pups	No. Female pups	Total No. pups	Total No. captures[a]	Capture success (%)[b]
Redeye	8/22–8/27	288	30	35	65	9	6	15	197	68.4
Skyline	9/15–9/19	300	14	18	32	1	3	4	82	27.3
Tuft's	8/15–8/20	300	26	29	55	1	2	3	140	46.7
		Total	70	82	152	11	11	22	419	

[a]Includes recaptures.

[b]Calculated by dividing total number of captures by the number of trap-nights.

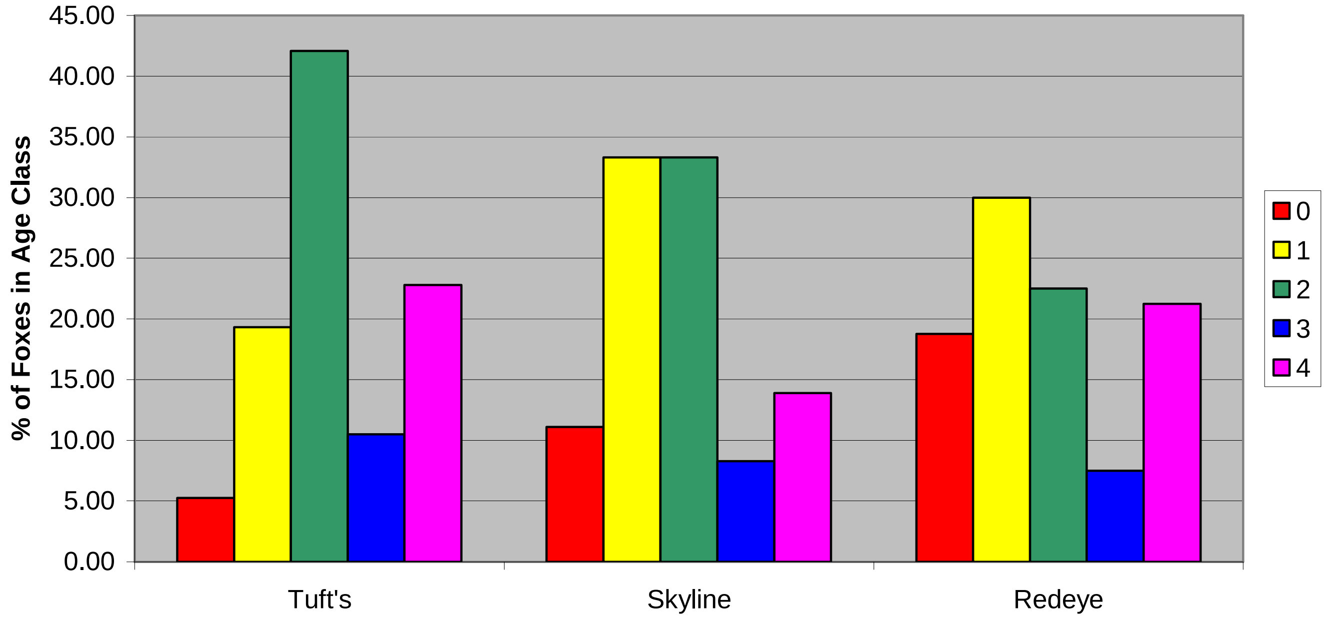


Fig. 4. Age class distribution by demography grid, 2008, San Nicolas Island, California.

Table 3. Mean weight (kg) of adult island foxes captured on grids, 2008, San Nicolas Island, California.

Grid	Sex	*n*	Mean	SD
Redeye	M	28	1.66	0.056
	F	33	1.71	0.290
Skyline	M	14	1.82	0.240
	F	18	1.58	0.092
Tuft's	M	24	2.05	0.353
	F	29	1.58	0.106
All foxes combined	M	66	1.68	0.035
	F	80	1.78	0.184

The most common physical "abnormalities" noted for the 173 foxes captured on grids in 2008 were matted or missing fur (38.9% of foxes captured; Table 4) and cuts, abrasions, and punctures injuries likely caused by intraspecific interactions. Three foxes had evidence of old fractures, one of which resulted in a missing foot. Seven individuals (3.9%) broke one or more teeth while in a trap. However, we only inspected foxes thoroughly for trap-related injuries on their initial capture; therefore, it is possible that additional tooth breakage may have occurred upon subsequent recapture.

Table 4. Physical abnormalities of island foxes captured on grids, 2008, San Nicolas Island, California. Based on examination of 173 foxes primarily upon first capture.

Physical "abnormality"	No. of foxes
Matted or missing fur	70
Minor cuts/abrasions	7
Partial missing ear(s)	5
Broken tooth (trap damage)	7
Lip injuries	8
Old fractures	3

Productivity

Across all grids, 26 (32.1%; n = 81) of the females showed signs of having lactated this year. The pup to adult female ratio for all grids combined was 0.27:1 (22 pups captured, 82 adult females captured). On the Redeye grid, where the majority of the pups were captured, the pup to adult female ratio was higher at 0.37:1.

Serology

For the 50 serum samples submitted for testing, 58% were positive for exposure to CAV, 70% for CDV and none were positive for CPV (Table 5).

Movements

In 2008, four animals moved into the Skyline grid from other grids (two each from Redeye and Tuft's), one onto Tuft's from Redeye, and three from Tuft's to Redeye. An animal was considered to have moved into a grid if the last time it was captured it was on another grid, regardless of how many years ago the previous capture occurred. One fox was captured on two different grids during the 2008 trapping period (see above).

Population Size, Density, Growth Rate, and Survivorship on Demography Grids

Adult fox population size estimates ranged from 39 on the Skyline grid to 74 on the Redeye grid (Table 5). Density estimates using values from program MARK/MMDM ranged from 10.7 foxes/km^2 on the Skyline grid to 21.5 foxes/km^2 on the Redeye grid (Table 5). Density estimates using program DENSITY provided lower values for all three grids, although there was substantial overlap in the 95% confidence intervals of the estimates from the two methods. (Table 6).

Population size estimates for 2008 indicate that the number of foxes on the grids increased from 2007 for both Redeye and Tuft's, but decreased on Skyline (Fig. 5-7). The population estimate for each grid for 2008 was higher than the nine-year mean for each grid. The mean annual rate of adult population change (λ) for 2000–2008 was >1 for all grids (Fig. 5–7).

Adult male survivorship averaged 68.9% (95% C.I. = 40.3–87.9%) and juvenile male survivorship averaged 77.8% (95% C.I. = 15.4–98.5%) (Fig.8). Adult female survivorship was similar to adult males at 63.1% (95% C.I. = 49.8–74.6%) and juvenile female survivorship at 80.6% (95% C.I. = 49.3–94.7%) was similar for juvenile males.

Table 5. Total number of adults captured, population estimates, effective trap area, and adult density estimates for the three demography grids, 2008, San Nicolas Island, California.

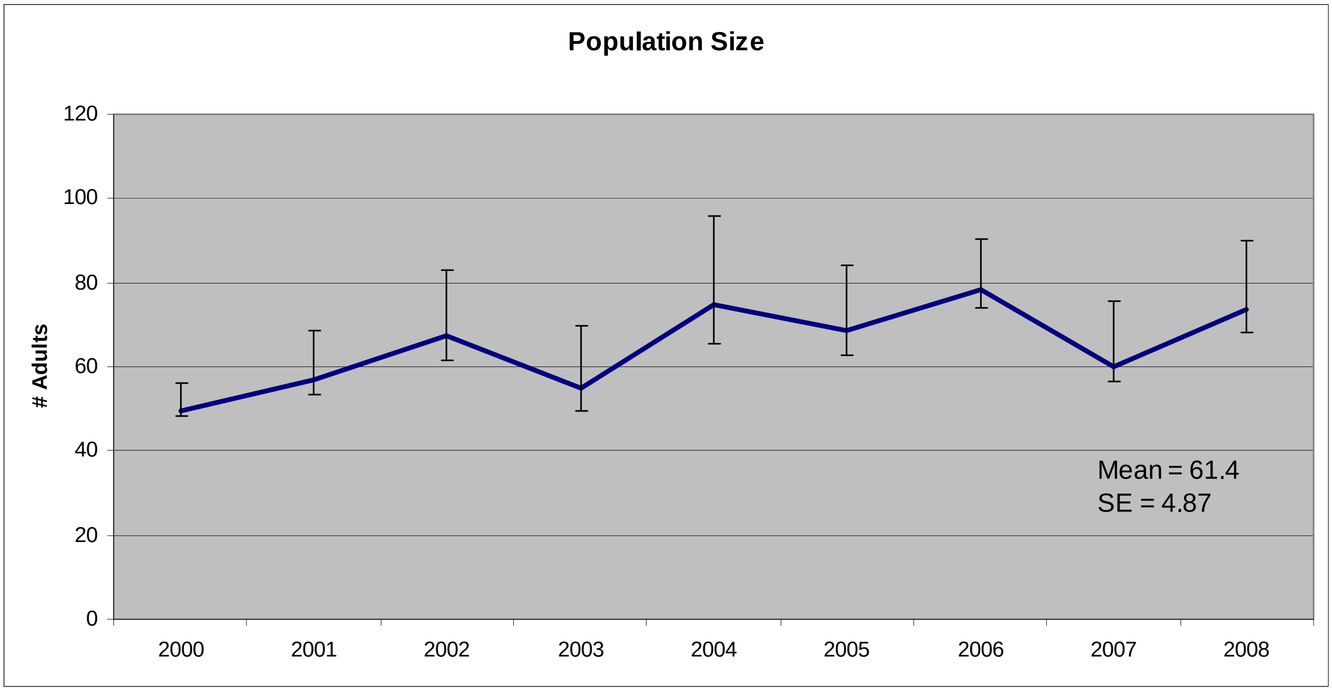
Grid[a]	No. Adults captured[b]	Population estimate	95% C. I.	Effective trap area (km^2)	Density estimate (foxes/km^2) based on population estimate[c]	Density estimate range based on 95% C.I. of population estimate (foxes/km^2)[d]
Redeye	65	74	68–90	3.44	21.5	19.8–26.1
Skyline	32	39	34–79	3.63	10.7	9.3–21.7
Tuft's	55	59	55–80	3.95	14.9	13.7–20.2

[a]See Fig. 2 or Fig. 3 for grid locations.
[b]One fox was captured on both Skyline and Redeye grids.
[c]Calculated as population estimate/effective trap area.
[d]Range calculated as population estimate/effective trap area, using the upper and lower bounds of the 95% C. I. of the population estimate.

Table 6. Island fox density calculated using program DENSITY with maximum likelihood function.

Grid[a]	No. Adults captured	Maximum likelihood density (foxes/km²)	SE	95% C.I. of density estimate
Redeye	65	15.9	2.27	12.2-21.2
Skyline	32	7.3	1.63	4.7-11.2
Tuft's	55	11.5	1.98	8.2-16.1

[a]See Fig. 2 or Fig. 3 for grid locations.



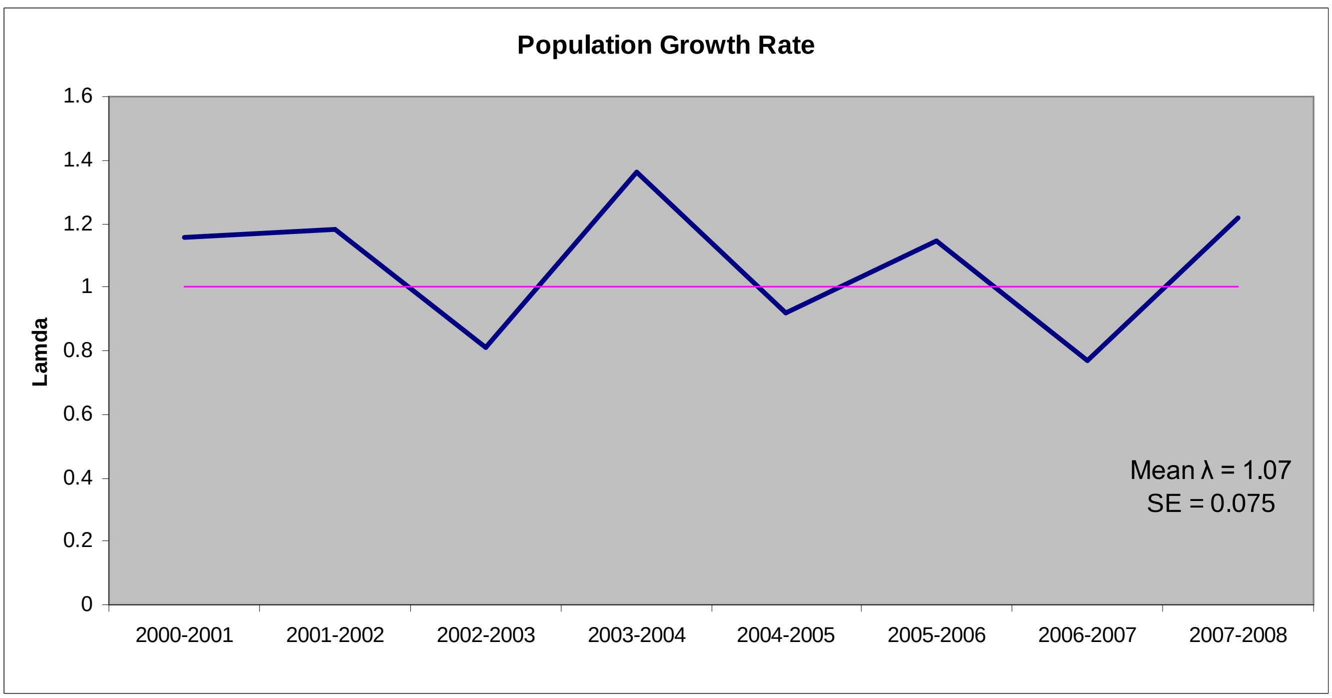
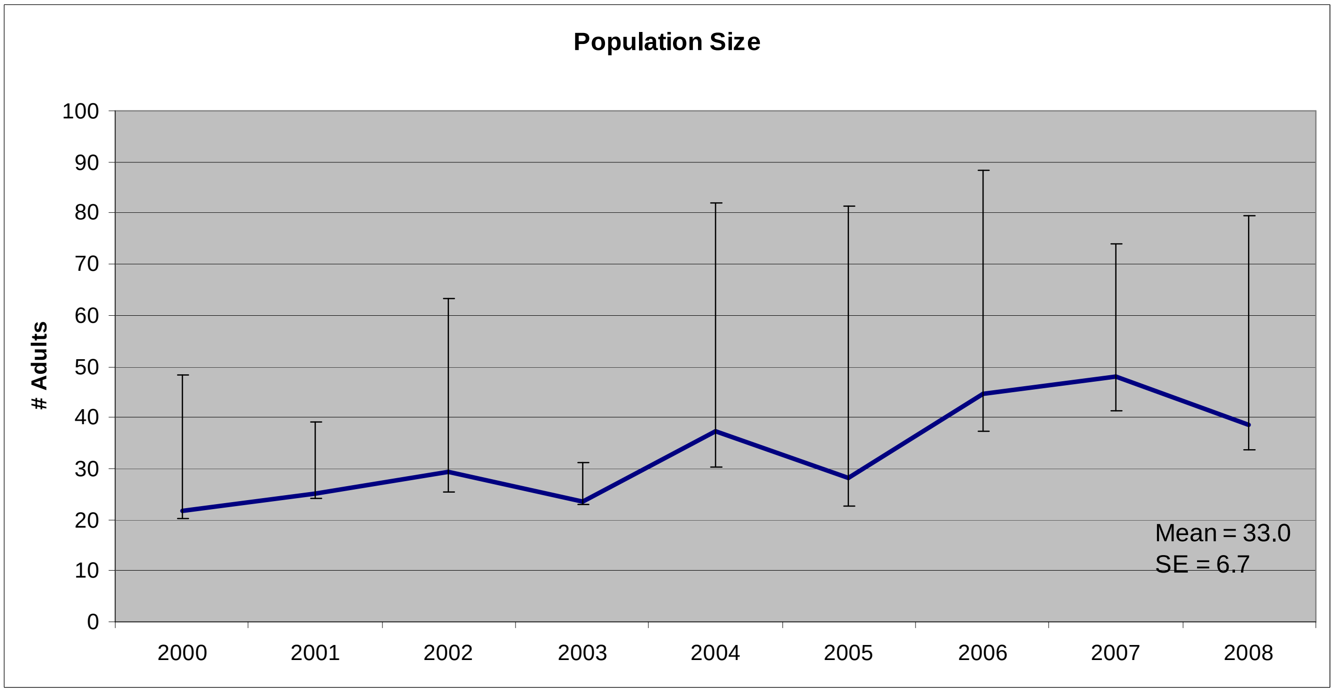


Fig. 5. Redeye grid adult population size and growth rate (λ) estimates 2000–2008, San Nicolas Island, California. Vertical lines represent 95% confidence intervals. A λ <1 indicates the population is declining and λ >1 indicates the population is increasing. A λ of 1 indicates a stable population (shown by horizontal line).



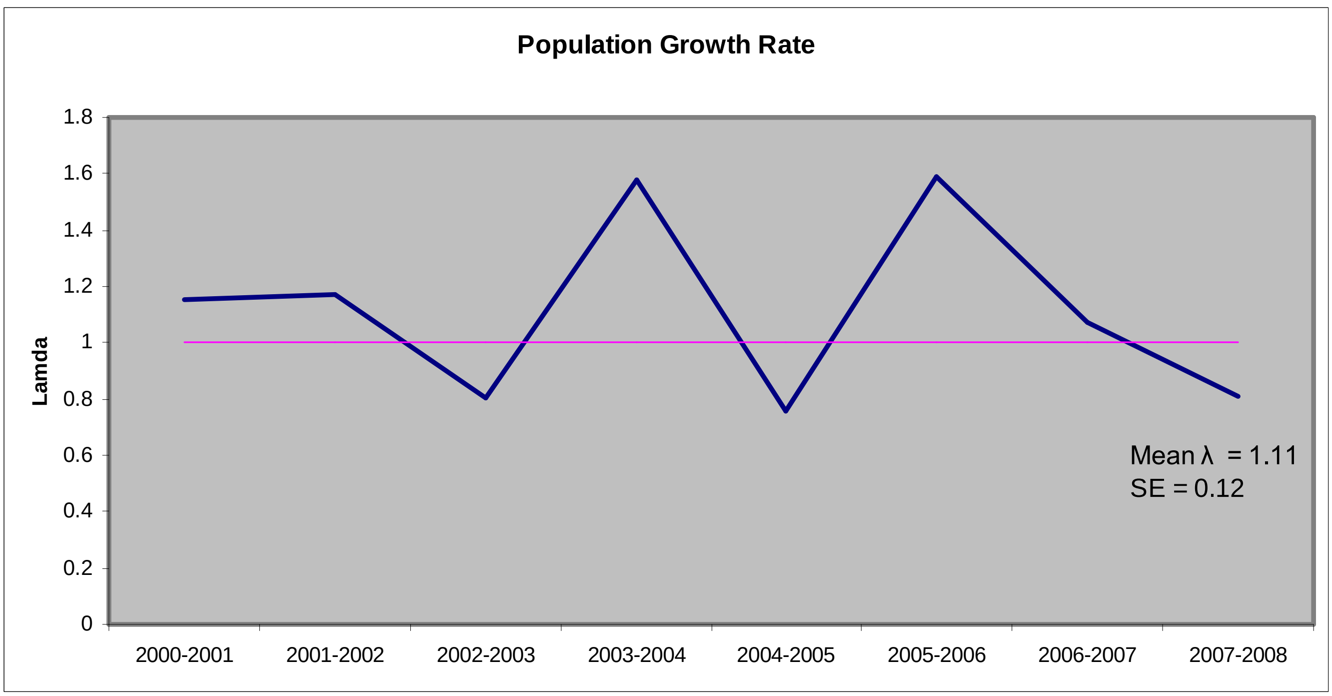


Fig. 6. Skyline grid adult population size and growth rate (λ) estimates 2000–2008, San Nicolas Island, California. Vertical lines represent 95% confidence intervals. A λ <1 indicates the population is declining and λ >1 indicates the population is increasing. A λ of 1 indicates a stable population (shown by horizontal line).

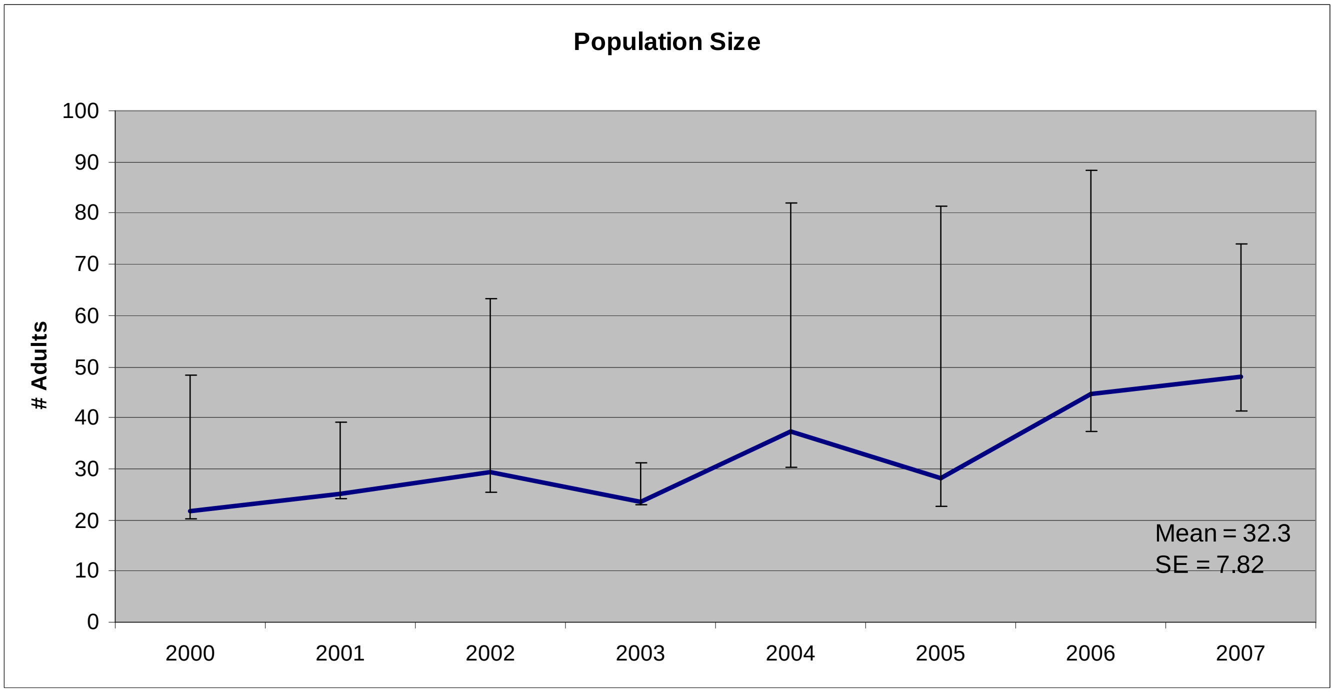


Fig. 7. Tuft's grid population size and growth rate (λ) estimates 2000–2008, San Nicolas Island, California. Vertical lines represent 95% confidence intervals. A λ <1 indicates the population is declining and λ >1 indicates the population is increasing. A λ of 1 indicates a stable population (shown by horizontal line).

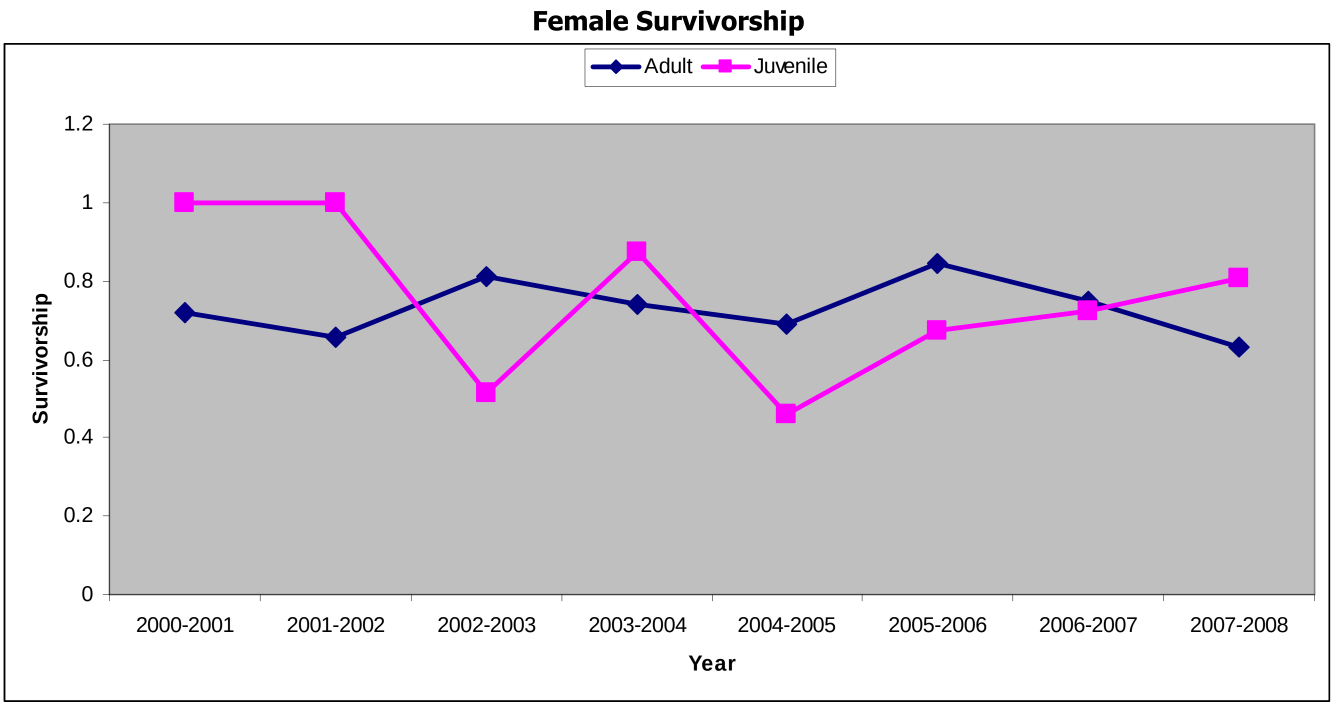


Fig. 8. Survivorship for adult and juvenile male and female foxes (all three trapping grids combined), 2000–2008, San Nicolas Island, California.

DISCUSSION

Results from the 2008 trapping efforts on San Nicolas Island found that foxes continue to maintain very high population density in all habitats sampled by the grids. We captured 151 adult foxes. This is very similar result compared to the 145 captured in 2007 and the 140 captured in 2006.

Population estimates for the three grids totaled 172 individual adults in 2008 compared to an updated estimate of 235 in 2007. As evidenced by the increased 2006 population estimate for the three grids from 157 adults, population estimation based on the capture-recapture history of individuals on each grid generally fluctuates each year. We therefore recommend that conclusions about the population's health be based on multi-year growth trends, which, while exhibiting some variance between years, has stayed relatively stable across the nine years of monitoring.

The finite rate of population increase, or Lambda, has varied between years, but has maintained a mean slightly greater than 1.0 for each of the grids for the eight between-year sampling periods. Along with the trend in estimated population size for each grid, this further suggests the population is relatively stable, with the variance being associated with differential survival and reproduction among years. As would be expected, estimates of annual survival rates for adult males and females have remained sufficiently high to provide the stable populations observed on the grids.

This year we employed two different techniques to calculate fox density on the grids. The first is the method we have used for the previous eight years and is determined using two values; the population estimate derived from mark-recapture data using program MARK, and the effective trap area calculated using a formula which incorporates the movements of foxes during the trapping period (mean maximum distance moved - MMDM). Comparisons made on San Clemente Island between grid trapping-based density estimates (using MARK and MMDM buffers) and telemetry-based home range estimates found that the former resulted in a density that was biased high (Garcelon 1999, Schmidt *et al.* 2004). This appears to be associated with foxes moving shorter distances during the trapping period (likely due to the presence of food in the traps) and therefore the effective trap area is smaller than it should be to provide an accurate density estimate.
For the 2008 data, we used a second method using program DENSITY (Efford et al. 2004). Rather than using a buffer strip around the trapping grid that is determined by the maximum distances animals moved during trapping, this program uses the locations where each animal is detected to fit a spatial model of the detection process. As it is unbiased by "edge effects" or incomplete detection it should provide a more accurate estimate of population density.

All of the density estimates derived from program DENSITY were lower than those calculated from the MARK/MMDM method. Estimates from program DENSITY were 26%, 31.7% and 22.8% lower than MARK/MMDM estimates for Redeye, Skyline and Tuft's, respectively. Using home ranges sizes determined by radio-telemetry for foxes on San Clemente Island, Schmidt et al. (2004) found that the MARK/MMDM method provided density estimates that were 19 – 55% higher than home range-based estimates. While similar telemetry data are not available for San Nicolas Island, if we assume similar behavioral response to trapping and comparable home range sizes, then the results from program DENSITY may be providing a more accurate estimate of fox density.

In conjunction with using program DENSITY to potentially obtain a more accurate method of calculating density on the grids, we would suggest continuing to calculate population estimates in program MARK to help provide population trend data as well as estimates of sex-specific annual survival rates.

Age structure of the fox population depicts some interesting patterns across the three grids. The Tuft's grid has typically had the highest proportion of older age-class foxes, although in 2008 the proportion degreased on that grid and the Redeye grid increased to nearly the same proportion of age class 4 foxes. Redeye increased from only 7.4% age class 4 foxes in 2007 to over 21.3% in 2008. However, the number of age-class 3 foxes decreased from 2007 to 2008 on Redeye, so the increase in an older age class may just be a result of a shift due to natural aging of individuals present on the grid.

Most of the foxes we examined appeared healthy. We found no indications infectious disease in the fox population. Physical anomalies that were observed in captured foxes were consistent with intra-specific aggression and capture-related injuries. Injuries associated with intra-specific aggression are not uncommon in island fox populations and would be expected, especially in areas of such high fox density. The occurrence of 13.4% of the animals being in poor body condition is not uncommon, as both older individual and females that had recently finished lactation can tend to be in poor body condition. The IWS staff veterinarian examined a sample of the foxes captured on the island and found no problems of concern.

Due to the late start on trapping the grids in 2008, we obtained less information on the reproductive status of female foxes compared to previous years. As most females that reproduced in 2008 would have likely have weaned their young a few months prior to our trapping, it was considerably more difficult to determine if adult females lactated in 2008. While some females still had some signs of reproduction (e.g., missing hair around mammary glands), we were less

confident about assigning reproductive status compared to previous years. The number of pups captured in 2008 (22) was similar to 27 captured in 2007.

Serology Testing

Virus exposure was assessed in 50 foxes via measurement of serum antibody levels to canine distemper virus (CDV), canine parvovirus (CPV), and canine adenovirus (CAV). Antibody levels are measured in serum and are reported in terms of titers, or dilutions at which antibodies can be detected. The higher the titer number, the more antibodies that are present.

Serology results suggest that CAV is currently actively circulating in the fox population. Testing indicated 58% of the foxes have been exposed at high enough levels to develop measurable titers, and most titers were high, suggesting a significant response to the virus. The proportion of antibody positive foxes is an increase from levels measured in this population in 2001-3 (40% had positive titers) (Clifford et al. 2006). In 2007, 81% of the foxes tested (n=47) had measurable titers for CAV on San Clemente Island (Garcelon et al. 2008).

Twenty-one foxes had serum antibody titers below measurable levels (<4), suggesting no recent exposure. The typical range of titers in domestic dogs (after vaccination) is 16 – 512. The large number of high titers (1:768 – 1:8192) in the SNI foxes suggests recent significant exposure has likely occurred.

Measurable CDV titers were present in 70% of the foxes tested. Utilizing Clifford et al.'s standard for classification, 54% would be considered positive, 16% of foxes tested would be classified as "suspect positive" for CDV exposure ≥8 but ≤16, and the remainder would be classified as "negative". This represents an apparent lower level of exposure to this virus in the population than was found in 2001-3 by Clifford et al. (32.8% "definite positive" and 41.8% "suspect positive"), but a greater proportion of individuals considered solidly positive for exposure.

No measurable CPV titers were present in any of the foxes tested. Direct comparison with results from Clifford et al. (2006) is not possible because the laboratories used different testing methods. However, the fact that 98.6% of the foxes showed some exposure to CPV in Clifford et al.'s study suggests that a lower percentage of the current fox population has been exposed to this virus than was the case at that time. CPV titers were only found in 6% of the foxes tested on San Clemente Island (Garcelon et al. 2008).

In summary, canine adenovirus appears to continue to circulate at high levels in this population, canine distemper virus (or a closely related virus) also appears to circulate at high levels (with a higher definitive positive than in 2001-3), and canine parvovirus was not detected in the population based on the laboratory technique used.

MANAGEMENT RECOMMENDATIONS

The largest risk currently facing San Nicolas Island foxes is the potential for an introduced disease to quickly decimate the population. San Nicolas Island foxes currently have two risk factors promoting susceptibility to an introduced disease. First, the sustained high density of foxes on the island represents a risk factor, as the persistence and spread of disease throughout a population is closely tied to population density (Anderson and May 1981, Finkenstadt and Grenfell 1998). San Nicolas Island foxes face a further risk since the population has extremely low genetic diversity (Aguilar *et al.* 2004). Low genetic diversity can be associated with reduced disease resistance, increased risk severity and length of disease epidemics in populations (Sprinbett *et al.* 2003). Levels of genetic diversity observed in San Nicolas Island foxes are caused by severe population bottlenecks leading to high levels of inbreeding. Such inbreeding is also associated with increased susceptibility to disease and environmental extremes (Keller and Waller 2002).

Due to the lack of foxes with measurable CPV titers, the current risk to the fox population from CPV may be high if a new strain were introduced to the island. However, the disease is rarely fatal except in juveniles. No CPV vaccines have been used in island foxes, and vaccination is not currently recommended by the Fox Health Expertise Group.

In order to reduce the risk of catastrophic disease, we incorporated a vaccination program associated with our trapping efforts. A large percentage of the animals caught were given canine distemper and rabies vaccinations. Modeling work by V. Baker and D. Doak (personal communication) has shown that, if the vaccinations are highly effective, this type of vaccination program is the most effective way of preventing an epidemic of those diseases. This vaccination program does not, however, provide any protection from potential disease threats other than canine distemper and rabies, and may not protect against all strains.

Another program currently underway on San Nicolas Island to test an automated survival monitoring system (Hudgens et al. 2007), may provide a mechanism for long-term monitoring of the fox population for early detection of disease outbreak. Part of this monitoring program includes developing specific triggers, based on types and frequency of mortalities, to further management actions. This type of monitoring system, in conjunction with prophylactic vaccination of a subset of foxes for canine distemper and rabies virus, may

help prevent the catastrophic decline of the fox population should one of these disease agents be introduced to the population.

We also advocate building a better understanding of San Nicolas Island fox feeding and breeding ecology to address two questions. First, what is the role of introduced species in maintaining high fox densities on San Nicolas Island? Understanding whether these resources act to promote longevity, reproduction, or buffer populations from environmental variation will allow predictions of the continued spread or control of these species on San Nicolas Island will impact foxes. Secondly, how does breeding potential change with fox age? Understanding which foxes contribute the most to pup production will help to elucidate whether some areas of the island act as population sinks (or sources). More importantly, such an understanding will provide information about mechanisms that maintain high fox densities but do not contribute to future fox generations. The answer to both questions will be necessary to make good predictions about how management of introduced food resources will impact foxes. Being able to separate and understand the roles of introduced species, and other island resources, in maintaining high population densities and contributing to future fox generations will allow the Navy to effectively manage these species without risking endangering San Nicolas Island foxes.

ACKNOWLEDGMENTS

Funding for the project was provided by the Naval Air Weapons Station, China Lake and the Department of the Navy under administration of Naval Facilities Engineering Command, Southwest, San Diego, California. We give special thanks to Grace Smith, SNI Natural Resources Manager, for her logistical support and valuable assistance to this project in a variety of ways. Gina Smith contributed logistical support on San Nicolas Island. We thank IWS employees Hower Blair, Francesca Ferrara, Jonathan Gunther, Marie Jacques, and T. Winston Vickers for their assistance with the fieldwork.

LITERATURE CITED

Aguilar, A., G. Roemer, S. Debenham, M. Binns, D. Garcelon, and R. K. Wayne. 2004. High MHC diversity maintained by balancing selection in an otherwise genetically monomorphic mammal. Proceedings of the National Academy of Sciences 101: 3490–3494.

Anderson, R. M., and R. M. May. 1981. The population dynamics of microparasites and their invertebrate hosts. Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences. 291:451–524.

California Department of Fish and Game. 1987. Five-year status report on the island fox (*Urocyon littoralis*). Unpublished report, California Department of Fish and Game, Sacramento, California. 7pp.

Clifford, D.L., J.A.K. Mazet, E.J. Dubovi, D.K. Garcelon, T.J. Coonan, P.A. Conrad and L. Munson. 2006. Pathogen exposure in endangered island fox (*Urocyon littoralis*) populations: implications for conservation management. Biological Conservation 131: 230-243.

Collins, P. W. 1982. Origin and differentiation of the island fox: a study of evolution in insular populations. M. A. thesis, University of California, Santa Barbara. 303pp.

Collins, P. W. 1993. Taxonomic and biogeographic relationships of the island fox (*Urocyon littoralis*) and gray fox (*U. cinereoargenteus*) from Western North America. Pages 351–390 *in* F. G. Hochberg, editor. Third California Islands Symposium: Recent advances in research on the California Islands, Santa Barbara Museum of Natural History, Santa Barbara, California.

Efford, M.G., D.K. Dawson and C.S. Robbins. 2004. DENSITY: software for analyzing capture-recapture data from passive detector arrays. Animal Biodiversity and Conservation 27.1: 217-228.

Finkenstadt, B., and B. Grenfell. 1998. Empirical determinants of measles metapopulation dynamics in England and Wales. 265:211–220.

Garcelon, D. K. 1999. Island fox population analysis and management recommendations. Unpublished Report submitted to: Southwest Div., Naval Fac. Eng. Command, San Diego, California. 57pp.

Garcelon, D. K., and G. A. Schmidt. 2005. Island Fox Monitoring and Demography on San Nicolas Island–2004. Unpublished report prepared by the Institute for Wildlife Studies, Arcata, California. 24pp.

Garcelon, D. K., L. Munson, T.W. Vickers and D. Simmons. 2008. Research study on the pathology and veterinary services for island foxes on San Clemente Island. Final report under agreement N62473-06-LT-R0057, Naval Facilities Engineering Command, Southwest, San Diego, CA. 8 pages + Appendices.

Gilbert, D. A., N. Lehman, S. J. O'Brien, and R. K. Wayne. 1990. Genetic fingerprinting reflects population differentiation in the California Channel Island fox. Nature 344:764–767.

Goldstein, D. B., G. W. Roemer, D. A. Smith, D. E. Reich, A. Bergman, and R. K. Wayne. 1999. The use of microsatellite variation to infer patterns of migration, population structure, and demographic history: An evaluation of methods in a natural model system. Genetics 151:797–801.

Hall, E. R. 1981. The mammals of North America, 2nd ed. John Wiley and Sons, New York.

Halverson, W. L., S. Junak, C. Schwemm, and T. Keeney. 1996. Plant communities of San Nicolas Island, California. Technical Report No. 55. National Biological Service, University of Arizona, Tucson, Arizona.

Hudgens, B., F. Ferrara, and D. Garcelon. 2007. Remote monitoring of island foxes. Report to DoD Legacy Program, May 2007. 13pp.

Juola F. A., G. A. Schmidt, P. B. Sharpe, and D. K. Garcelon. 2002. Island Fox Monitoring and Demography on San Nicolas Island–2001. Unpublished report *prepared by* the Institute for Wildlife Studies, Arcata, California. 34pp.

Keller L. F., and D. M. Waller. 2002. Inbreeding effects in wild populations. TRENDS in Ecology and Evolution 17:230–241.

Kendall, W. L., K. H. Pollock, and C. Brownie. 1995. A likelihood-based approach to capture-recapture estimation of demographic parameters under the Robust Design. Biometrics 51:293–308.

Kendall, W. L. 2001. The Robust Design for capture-recapture studies: analysis using program MARK. Pages 357–360 in Proceedings of the 2nd International Wildlife Management Congress. The Wildlife Society, Bethesda, Maryland, USA.

Kohlmann, S. G., G. A. Schmidt, R. C. Wolstenholme, and D. K. Garcelon. 2003. Island fox recovery efforts on Santa Catalina Island, California, October 2001–October 2002, Annual Report. Unpublished report by the Institute for Wildlife Studies, Arcata, California for the Ecological Restoration Department, Santa Catalina Island Conservancy, Avalon, California. 83pp.

Kohlmann, S. G., G. A. Schmidt, and D. K. Garcelon. 2005. A population viability analysis for the Island Fox on Santa Catalina Island, California. Ecological Modeling 183:77–94.

Moore, C. M., and P. W. Collins. 1995. *Urocyon littoralis*. Mammalian Species, No. 489. 7pp.

Pollock, K. H. 1982. A capture-recapture design robust to unequal probability of capture. Journal of Wildlife Management 46:757–760.

Pollock, K. H., J. D. Nichols, J. E. Hines, and C. Brownie. 1990. Statistical inference for capture–recapture experiments. Wildlife Monographs 107.

Roemer, G. W., D. K. Garcelon, T. J. Coonan, and C. Schwemm. 1994. The use of capture-recapture methods for estimating, monitoring, and conserving island fox populations. Pages 387–400 in W. L. Halverson and G. J. Maender, editors. The Fourth California Channel Islands Symposium: Update on the Status of Resources. Santa Barbara Museum of Natural History, Santa Barbara, California.

Roemer, G. W., T. J. Coonan, D. K. Garcelon, J. Bascompte, and L. Laughrin. 2001. Feral pigs facilitate hyperpredation by golden eagles and indirectly cause the decline of the island fox. Animal Conservation 4:307–318.

Schmidt, G. A., and D. K. Garcelon. 2003. Island Fox Monitoring and Demography on San Nicolas Island–2002. Unpublished report *prepared by* the Institute for Wildlife Studies, Arcata, California. 22pp.

Schmidt, G. A., and D. K. Garcelon. 2004. Island Fox Monitoring and Demography on San Nicolas Island–2003. Unpublished report *prepared by* the Institute for Wildlife Studies, Arcata, California. 24pp.

Schmidt, G. A., B. Willson, and D. K. Garcelon. 2004. Island fox monitoring and research on Naval Auxiliary Landing Field, San Clemente Island, California. Unpublished report *prepared by* the Institute for Wildlife Studies, Arcata, California. 63pp.

Schmidt, G. A., B. R. Hudgens, and D. K. Garcelon. 2007. Island Fox Monitoring and Demography on San Nicolas Island–2006. Unpublished report *prepared by* the Institute for Wildlife Studies, Arcata, California. 26pp.

Schmidt, G. A., B. R. Hudgens, and D. K. Garcelon. 2006. Island Fox Monitoring and Demography on San Nicolas Island–2005. Unpublished report *prepared by* the Institute for Wildlife Studies, Arcata, California. 24pp.

Springbett, A. J., K. MacKenzie, J. A., Woolliams, and S. C. Bishop. 2003. The contribution of genetic

diversity to the spread of infectious diseases in livestock populations. Genetics 165:1465–1474.

Suckling. K., and D. K. Garcelon. 2000. Petition to list four island fox subspecies as endangered species. Formal petition to list the San Miguel Island fox (*Urocyon littoralis littoralis*), Santa Rosa Island fox (*U. l. santarosae*), Santa Cruz Island fox (*U. l. santacruzae*), and the Santa Catalina Island fox (*U. l. catalinae*) as "endangered" throughout their range. *Prepared by* the Center for Biological Diversity, Tucson, Arizona and the Institute for Wildlife Studies, Arcata, California *for* the United States Department of the Interior and the United States Fish and Wildlife Service. 24pp.

Timm, S. F., J. M. Stokely, T. B. Gehr, R. L. Peebles, and D. K. Garcelon. 2000. Investigation into the decline of island foxes on Santa Catalina Island. Unpublished report *prepared by* the Institute for Wildlife Studies *for* the Ecological Restoration Department, Santa Catalina Island Conservancy, Avalon, California. 32pp.

Wayne, R. K., S. B. George, D. Gilbert, P. W. Collins, S. D. Kovach, D. Girman, and N. Lehman. 1991. A morphologic and genetic study of the island fox, *Urocyon littoralis*. Evolution 45:1849–1868.

White, G. C. and K. P. Burnham. 1999. Program MARK: Survival estimation from populations of marked animals. Bird Study 46 Supplement 120–138.

Wilson, D. E., and D. M. Reeder. 1993. Mammal species of the World: a taxonomic and geographic reference, 2nd ed. Smithsonian Institution Press, Washington, DC.

Wilson, K. R., and D. R. Anderson. 1985. Evaluation of two density estimators of small mammal population size. Journal of Mammalogy 66:13–21.

Wood, J. E. 1958. Age structure and productivity of a gray fox population. Journal of Mammalogy 39:74–86.

APPENDIX A

Island fox demography grids showing trap numbers and locations, San Nicolas Island, California.

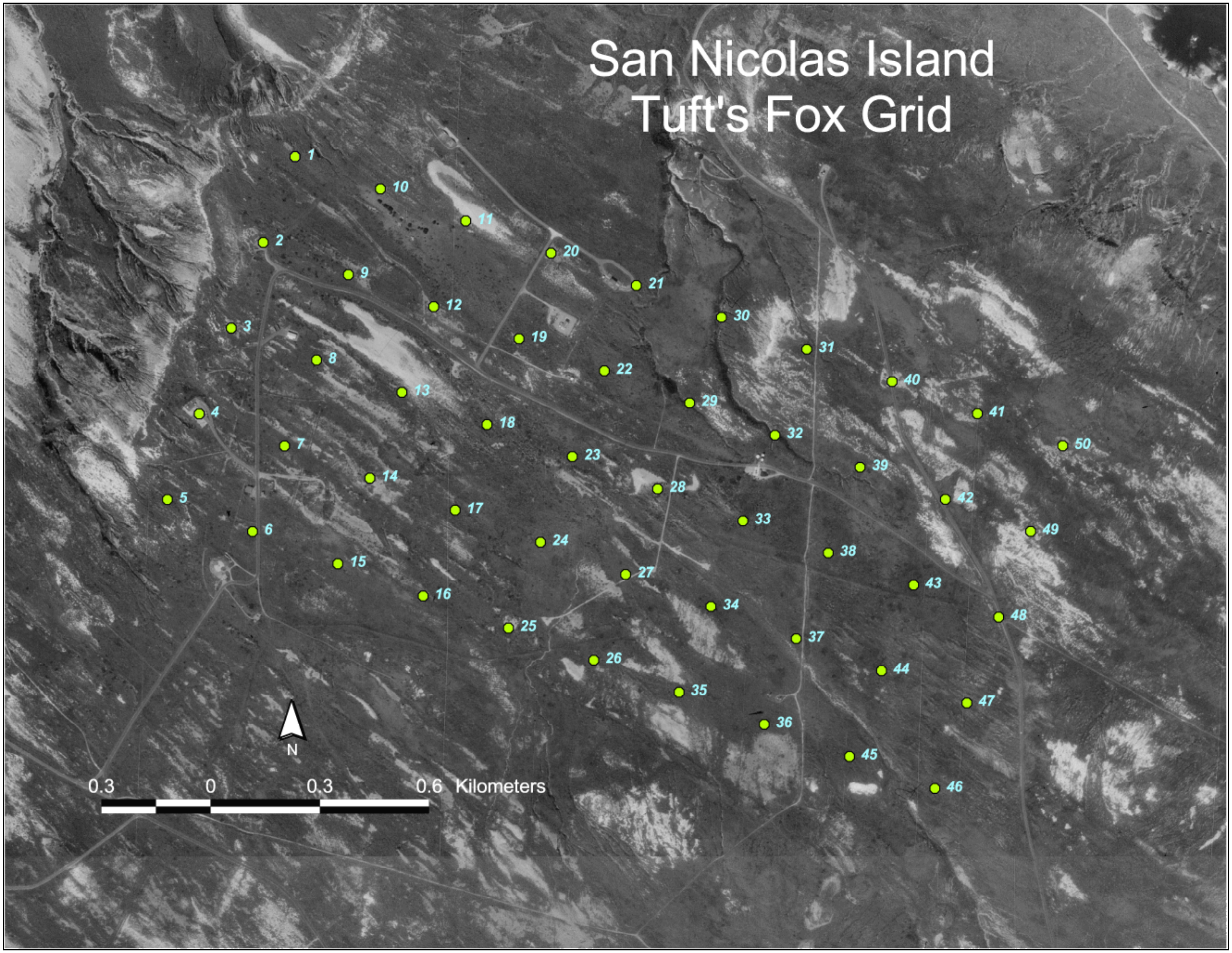


Figure A-1. Tuft's island fox demography grid, San Nicolas Island, California.

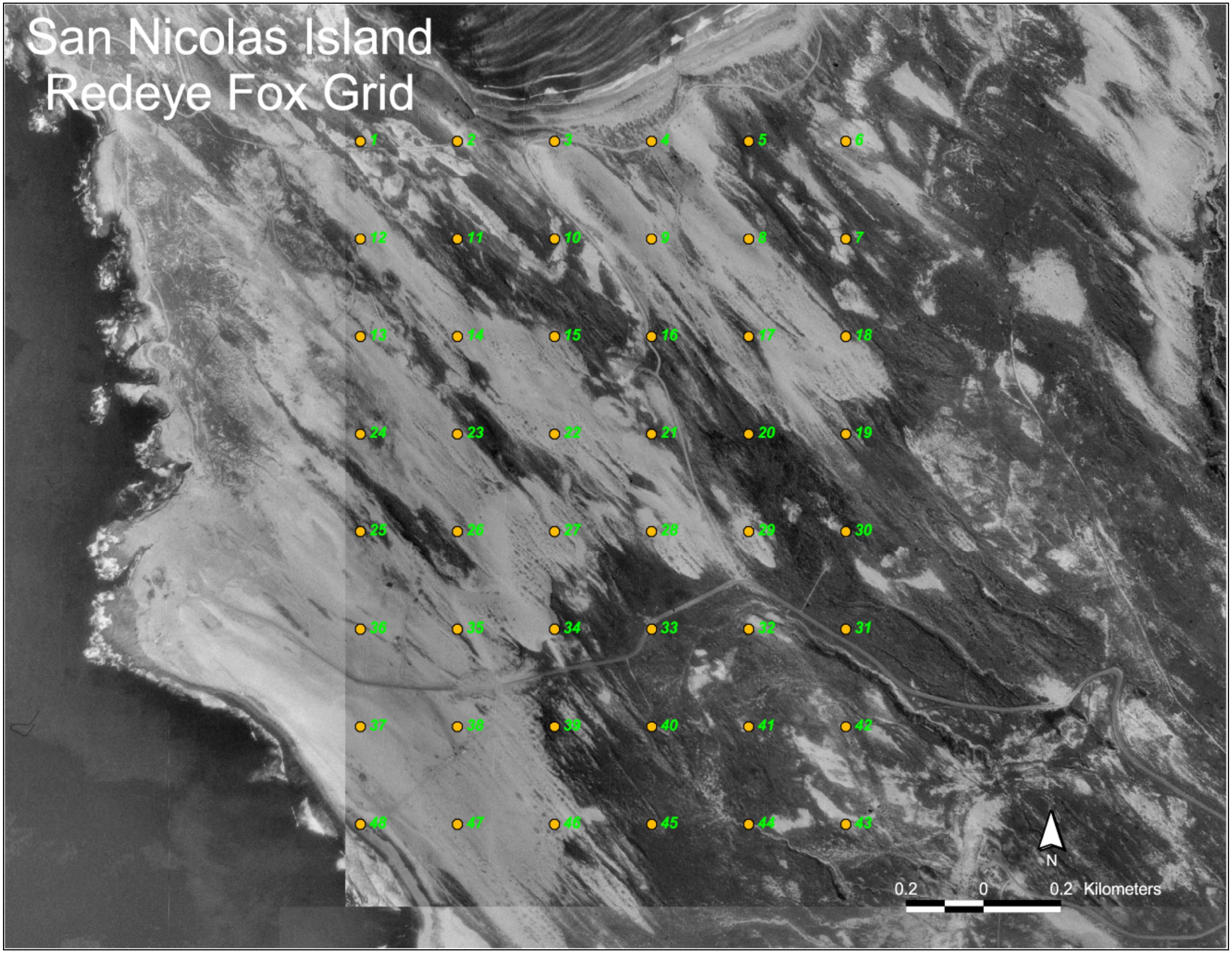


Figure A-2. Redeye island fox demography grid, San Nicolas Island, California.

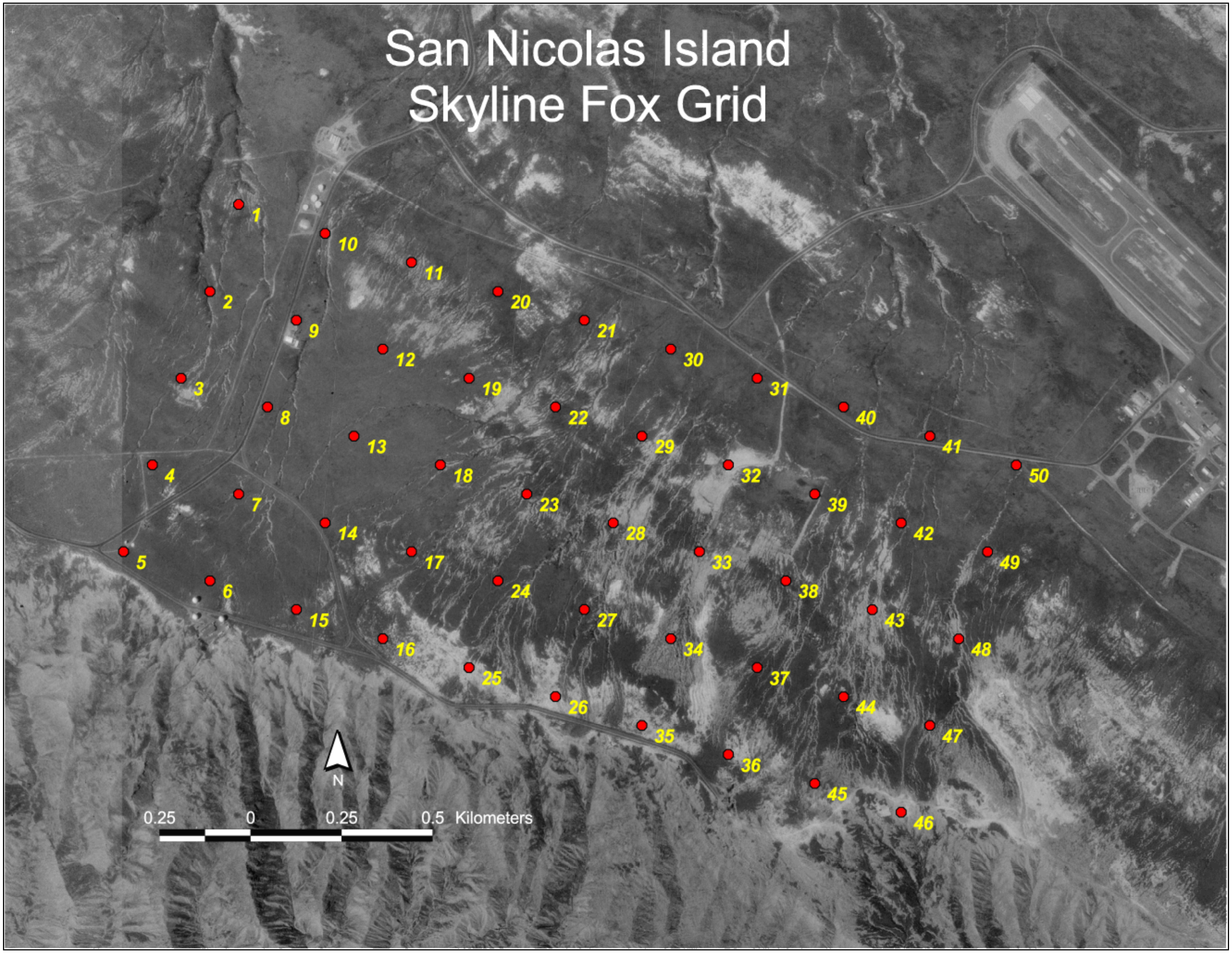


Figure A-3. Skyline island fox demography grid, San Nicolas Island, California.

APPENDIX B

Serum titers for canine adenovirus, canine distemper virus, and canine parvovirus from blood samples collected on San Nicolas Island in 2008.

Serum titers for canine adenovirus (CAV), canine distemper virus (CDV) and canine parvovirus (CPV) from blood samples collected on San Nicolas Island in 2008.

ID	CAV	CDV	CPV
607	<4	48	<20
2776	384	16	<20
0495D	<4	8	<20
04E09	3072	12	<20
07D4F	6144	<8	<20
14919	384	24	<20
14B0B	<4	16	<20
16303	<4	32	<20
21939	64	32	<20
22513	6144	12	<20
27336	384	<8	<20
31060	<4	<8	<20
33915	6	24	<20
33A07	3072	16	<20
35F71	<4	24	<20
42377	96	8	<20
4412A	4096	12	<20
44365	48	6	<20
4593F	512	8	<20
50867	1536	<8	<20
55544	3072	24	<20
56E46	<4	<8	<20
62F29	4096	12	<20
65C08	<4	8	<20
66471	<4	8	<20
6663A	<4	16	<20
70463	<4	64	<20
75356	8192	16	<20
75627	1536	24	<20
7780D	<4	4	<20
83846	<4	<8	<20
84231	<4	8	<20
85D58	1536	<4	<20
87356	<8	<4	<20
87B0F	<4	24	<20
91F67	1024	6	<20
92537	<4	<8	<20
95963	<4	<8	<20
A0A04	<4	24	<20
A4C70	1024	16	<20
A4D03	96	12	<20
B1562	1024	<8	<20
B581C	768	32	<20
C195C	768	12	<20
C3F06	24	24	<20
D5A57	3072	8	<20
E235D	4096	<8	<20
F4450	<4	<8	<20
F4C71	768	12	<20
F7D73	<4	8	<20